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NAVWEPS REPORT 7363

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THE THERMAL BEHAVIOR OF EXPLOSIVES SUBJECTED TO SIMULATED AERODYNAMIC HEATING, III (U)

25 JULY 1961

U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, MARYLAND

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THE THERMAL BEHAVIOR OF EXPLOSIVES SUBJECTED TO SIMULATED AERODYNAMIC HEATING, III (U)

Prepared by:

N. L. Coleburn
B. E. Drimmer

Approved by: [signature]
Chief, Explosion Dynamics Division

ABSTRACT: Ignition time and heat flow have been measured for six explosives, tested in one-dimensional, unconfined analogues of cylindrical, steel-cased warheads. They were unidirectionally heated at rates corresponding to aerodynamic heating associated with the sea-level flight of supersonic missiles and aircraft at low Mach numbers. With heating rates up to 100° C per minute the runaway reaction occurs as a rapid deflagration beginning on the explosive's surface touching the steel case. When a temperature of 455° C was applied to the outer surface of the 1-cm thick steel warhead case, the explosive ignition times were:

Tetryl	- 135 sec
TNT	- 164 sec
PBX N-1	- 180 sec
Pentolite	- 139 sec
H-6	- 169 sec
Composition B	- 202 sec.

PBX 9404 showed a small but inconclusive increase in impact-hammer sensitivity (the 50% point changed from 26 to 31 cm) after three thermal cycles between 20° and 200° C.

Explosions Research Department
U. S. NAVAL ORDNANCE LABORATORY
WHITE OAK, MARYLAND

NAVWEPS Report 7363 25 July 1961

This report on six explosives is the third in a series which has described work done under Task RUME 3E012/212 1/F008 10 004, Properties of Explosives (formerly called Explosives Applied Research) for the purpose of gaining a clearer understanding of the ignition behavior of explosives heated rapidly to temperatures associated with aerodynamic heating during flights of missiles and aircraft at supersonic speeds. The first report, NAVORD Report 6216, outlined the experimental approach and gave data on the plastic-bonded explosive PBX 9404, and the aluminized explosive H-6. The second, NAVWEPS Report 7338, treated work done to determine the ignition properties of the heat-resistant explosive, DATB.

W. D. COLEMAN
Captain, USN
Commander

C. J. Aronson

C. J. ARONSON
By direction

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THE THERMAL BEHAVIOR OF EXPLOSIVES SUBJECTED TO SIMULATED AERODYNAMIC HEATING, III (U)

1. INTRODUCTION

New problems involving the thermal response of explosives arise from the aerodynamic heating of warheads during supersonic flights of military aircraft and guided missiles. The extent of this response could readily affect the safety of aircraft and personnel, and in addition could modify seriously the performance of the heated warhead when it reaches its target. This report is the third of a series (1,2) in which we have described experimental work done to develop a clearer understanding of the ignition behavior of some of the explosives which are of interest to ordnance engineers designing such warheads.

To simplify the theoretical analysis, we have attacked these problems experimentally by designing our studies to conform to a one-dimensional heat flow problem. In this model a heat pulse is rapidly imposed over the entire surface of a steel plate (simulating the missile wall) supporting a slab of solid explosive. For at least the central portion of the system, the heat is conducted unidirectionally through the steel, into the explosive. In the present work we have obtained data for six explosives wherein the steel missile wall was subjected to an initial forcing temperature of 455° C: TNT, Pentolite, Tetryl, Composition B, H-6 and PBX N-1. In addition an impact-hammer sensitivity test was run on thermally-cycled PBX 9404 to determine if the warhead in a missile, or an externally carried aircraft bomb, subjected to elevated temperatures by aerodynamic heating and then cooling on return to base, could still be considered safe.

2. EXPERIMENTAL ARRANGEMENT

The method described in detail in reference 1 was used in the present experiments: an approximately cylindrical brass block, 30.5 cm high, 30.5 cm in diameter at its base and 25.4 cm in diameter at its top, was preheated to a given "initial forcing temperature". A 20.3-cm diameter steel disc, 1-cm thick, supporting a 17.8-cm diameter explosive disc, 2.5-cm thick, was then quickly placed on top of the brass. (A 1-cm thick replaceable copper disc, with two 0.16 cm by 0.16 cm, 8.9-cm long grooves for thermocouples on each face, was placed first on the brass just prior to the experiment.) (See Figure 1.)

It was assumed that the heat flow was unidirectional along the central axis of the test explosive disc. The reasonable assumption was then made, in view of the large radius of the disc, that the heat flow was unidirectional at least out to 1.27 cm from the disc axis (i.e. for at least 14 per cent of the radius). Accordingly, small diameter (less than 0.1 cm) iron-constantan thermocouples were imbedded in the explosive at different, known depths, on the circumference of a circle 1.27-cm in radius, Figure 2. The couple leads were buried in narrow grooves machined into the disc from its periphery. Powdered explosive, the same as the test disc, was gently pressed into the grooves to hold the couples in place and to minimize the disturbance to the heat flow caused by the grooves.

3. RESULTS

The experimental data obtained for the six explosives heated to ignition are summarized in Table I. The high thermal gradient observed in the heated explosive implies that the highest temperature experienced by the non-burning explosive occurred at the steel-explosive interface, just prior to ignition. Therefore the explosive "ignition temperature" was considered to be the temperature recorded at the steel-explosive interface at the time of the visual observation or temperature-recorder indication of evidence of rapid burning. The ignition time ("cycle duration" of Table I) is the time recorded between the initial copper-steel contact and this evidence of deflagration of the explosive sample. Temperature-time profiles for the tested explosives are displayed in Figures 3 to 9. The 50% impact-hammer sensitivity test results for PBX 9404 after this explosive had been heated in three thermal cycles are listed in Table II.

The following paragraphs describe in detail the test results obtained for the individual explosives.

3.1 TNT; density = 1.62 g/cm3.

Figure 3 shows the temperature-time observations made on cast TNT under an initial forcing temperature of 456° C. This explosive was tested to study the effect of the phase change (melting point, 80.5° C) on the results. However, the experimental arrangement was such as to prevent detailed measurements of this effect. Beginning at about 45 seconds, at least some of the explosive (in contact with the steel disc) exceeded the melting point. By the time deflagration of the sample was detected, 164 seconds after steel-copper contact,

an explosive layer about 7 mm thick experienced temperatures exceeding the melting point. While steel sides had been placed around the explosive to minimize flow of the liquid phase, the density difference between the liquid and solid phases (plus some fluid flow around the solid phase) must have modified the initial experimental geometry. Thus, thermocouple E-2, starting 2 mm away from the steel interface, may have moved toward, or away from the steel by the end of the experiment.

3.2 Pentolite (PETN/TNT 50/50); density = 1.65 g/cm^3.

The temperature-time profile of Figure 4 shows the deflagration of cast pentolite occurring 139 seconds after the steel outside wall of the missile was subjected to an initial forcing temperature of 444° C. The sudden rise in the temperature of the 2-mm layer at 80 seconds could be due to a geometry change affecting thermocouple T_{E-2}; however, there are indications of possible self-heating occurring twenty seconds later, as seen by the sudden inflections in the other thermocouple recordings.

3.3 Tetryl; density = 1.61 g/cm^3.

Two samples of tetryl, under initial forcing temperatures of 450° C, ignited in 132 seconds for one sample, and 138 seconds for the other, at which time the steel-tetryl interface reached 221 ± 2° C. Typical results are shown in Figure 5; when this sample deflagrated, the temperature at the 2-mm depth was only 110° C.

3.4 H-6 (RDX/TNT/Al/Wax - 47/31/22/5); density = 1.75 g/cm^3.

In Figure 6, the erratic behavior of thermocouple T_{E-1} (indicated by the broken line) is probably due to the melting of TNT, a major component of H-6. Under an initial forcing temperature of 457° C, the steel-H-6 interface was heated rapidly from its initial temperature of 100° C to 200° C in two minutes. When the sample deflagrated at 169 seconds, the interface temperature had reached 231° C while the interior of the explosive was still relatively cool, thermocouple T_{E-7} recording only 40° C.

3.5 PBX N-1 (RDX/Al/Nylon - 66/25/9); density = 1.77 g/cm^3.

The heating curves for these two samples are shown in Figures 7 and 8. Sample 1, heated with an initial forcing temperature of 424° C, deflagrated after 270 seconds (Figure 7). Sample 2, driven with an initial forcing temperature of 455° C

(Figure 8) deflagrated after only 180 seconds. The steel-explosive interface temperatures at ignition, for both tests were within 4° C of 216° C indicating that the previous history of the samples played only a minor role in determining their ignition temperatures (Sample 1 had received two 5-minute thermal cycles under forcing temperatures of 100° C and 200° C; while Sample 2 received three thermal cycles: 100°, 200°, and 300° C).

3.6 Composition B (RDX/TNT/Wax - 60/40/1); density = 1.68 g/cm3.

Some of the thermocouples in this test "misbehaved", as shown in Figure 9. It is not clear exactly why thermocouple T_{E-2} held steady at 800 C for about 30 seconds, and at the same time T_{E-3} held steady at about 70° C for about 50 seconds. It would be tempting to explain the 80° plateau as due to the melting of TNT; however, during the test of TNT alone, Figure 3, no such plateau was observed. Another mystery is the unusually high ignition temperature, 285° C, reached at the steel-explosive interface. This compares with the 226° C (± 5° C) observed for the other TNT-based explosives tested in this series. An examination of the records, instruments, calibrations showed all in order; nevertheless the shape of the heating curves, coupled with the unusual temperatures observed, leads one to place a low level of reliance on these Composition B results.

3.7 Impact Sensitivity of PBX 9404 after Thermal Cycling.

Impact-hammer sensitivity tests were run on PBX 9404 in an effort to measure the change in shock sensitivity due to thermal cycling. Two samples were heated in the same geometry as in the above deflagration tests, until the steel-explosive interface reached about 180° C, at which time the test rig was raised from the brass block. Heating of the samples was repeated one day apart, for three cycles, after which time several grams of explosive were obtained from the upper and lower surfaces of the explosive discs. The 50% impact-hammer sensitivity heights are compared in Table II, with a sample of PBX 9404 that had not been heated. No difference in sensitivity was observed between the top or bottom (hotter) parts of the test disc: one sample had 50% impact heights of 29 cm, the other 33 cm. These are slightly higher than the 26 cm obtained for the unheated material, a value which agrees with previous NOL data (3) for this explosive.

4. DISCUSSION

In our tests the surfaces of the unconfined explosive were heated rapidly (up to 100° C per minute). The resulting rapid temperature rise affected an explosive layer only a few millimeters thick, so that at the time of ignition, most of the explosive had experienced relatively small increases in temperature.

Evidence of self-heating was not clearly defined. The heating curves for Pentolite and Composition B (Figures 4 and 9) contain curves which might be interpreted as due to self-heating. However, since ignition occurred well after the temperatures in the first few millimeters of explosive were significantly above the melting point of TNT, possible motion of the couples within the liquid phase could have caused the erratic behavior of the temperatures. Tetryl (melting point = 129° C) burned rapidly when the temperatures within the first 2-mm explosive layer were between 110° C and 230° C, showing that its runaway reaction also began within the liquid phase.

When H-6 and PBX N-1 (sample 2) were heated at the same rate, the ignition times of the two explosives, 175 seconds (± 5 seconds), and ignition temperatures 225° C (± 5° C) were essentially the same. These data indicate that these aluminized explosives are reasonably similar in their responses to such thermal shocks.

On the other hand, in the test with Composition B (which differs from H-6 only in aluminum content) the steel-explosive interface thermocouple recorded 225° C approximately 80 seconds sooner than in the case of H-6. The higher thermal conductivity of the aluminized explosive is believed to be responsible for this time difference.

Comparison of the impact test results of 29 cm and 33 cm for the two thermally cycled PBX 9404 samples, with the 26.4 cm obtained for the control sample, indicates a small decrease in sensitivity due to such cycling. However, the standard deviations were too large to permit a firm conclusion that the change had resulted from thermal cycling.

5. CONCLUSIONS

In these tests ignition of the unconfined explosive usually began as a runaway reaction at the steel-explosive interface. This reaction was a rapid burning which, in our

tests, never built up to a detonation. With the high rates of heat input used in these tests, the explosive layers more than 3 or 4 mm from the surface experienced relatively little temperature rise before ignition. This confirms our previous conclusion (1) that deflagration of the explosive may be significantly delayed by an insulator layer only one or two millimeters thick. It also suggests the important safety concept that detonation probabilities in a fire could be minimized by designing ordnance to have minimum confinement during the fire, thus permitting a deflagration to consume the explosive: blowout plugs or other gas-venting systems might be useful for this purpose.

Under an initial forcing temperature of 450° C, deflagration of tetryl and pentolite occurred at essentially the same time, 135 (± 4) seconds, at which time the final steel-explosive interface temperatures were 221° C (± 2° C). TNT lasted 164 seconds under these same thermal conditions, with T_{S-E} recording 225° C. Composition B burned in 202 seconds, with the final interface temperature at an unexpected high of 285° C.

H-6 and PBX N-1 exhibited similar thermal characteristics, (neglecting the phase change of TNT in H-6), each deflagrating in 175 ± 5 seconds, under an initial forcing temperature of 455° C.

Increasing the thermal conductivity of explosives by adding aluminum results in an increase in the time required for the steel-explosive interface temperature to attain higher temperatures. (Thus the Composition B-steel interface reached 225° C eighty seconds sooner than the H-6-steel interface.)

The 50% impact sensitivity height of two PBX 9404 samples after repeated thermal cycling to about 180° C were 29 and 33 cm. This small increase over the 26-cm impact height for normal unheated samples cannot be considered statistically significant.

6. ACKNOWLEDGMENTS

The assistance of E. A. Duck in preparing the experimental arrangements and conducting the tests, and the cooperation of H. Heller and S. Duck who made the impact-hammer sensitivity measurements, are noted with thanks.

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TABLE I

Summary of Experimental Data: Heating-to-Deflagration of Explosives

Explosive Sample	Fig. No.	Thermal Cycle	Cycle Duration (sec)	Initial Temp. °C	Initial Forcing Temp. °C (T_{Cu})	Final Forcing Temp. °C (T_{Cu})	Final Steel Wall Temp. °C (T_{Cu-S})	Final Steel Explosive Interface Temp. °C (T_{S-E})
TNT	3	1	164	13	456	390	290	225
Pentolite	4	1	139	23	444	360	230	222
Tetryl (Sample No. 1)	-	1	138	20	450	385	230	220
Tetryl (Sample No. 2)	5	1	132	28	450	369	235	223
H-6	6	1	169	14	457	350	244	231
PBX N-1 (Sample No. 1)	7	3	270	7	424	344	224	212
PBX N-1 (Sample No. 2)	8	4	180	10	455	365	260	220
Composition B	9	1	202	15	458	362	300	285

TABLE II

Impact Sensitivity of PBX 9404 after Thermal Cycling

Explosive Sample	Thermal Cycle	Cycle Duration (sec)	Initial Temp (°C)	Final Steel-Explosive Interface Temp. (°C)	Final Temp. at Sample Top (°C)	50% Impact Sensitivity (cm)
1	First	203	7	190	31	- - -
1	Second	135	3	175	21	- - -
1	Third	130	14	180	24	Recovered Top: 29 cm (σ = ±0.14 log units) Bottom: 29 cm (σ = ±0.09 log units)
2	First	200	5	160	27	- - -
2	Second	270	10	170	31	- - -
2	Third	261	10	170	32	Recovered Top: 33 cm (σ = ±0.07 log units) Bottom: 33 (σ = ±0.12 log units)
3	- -	- -	-	- -	- -	26 cm (σ = ±0.07 log units)

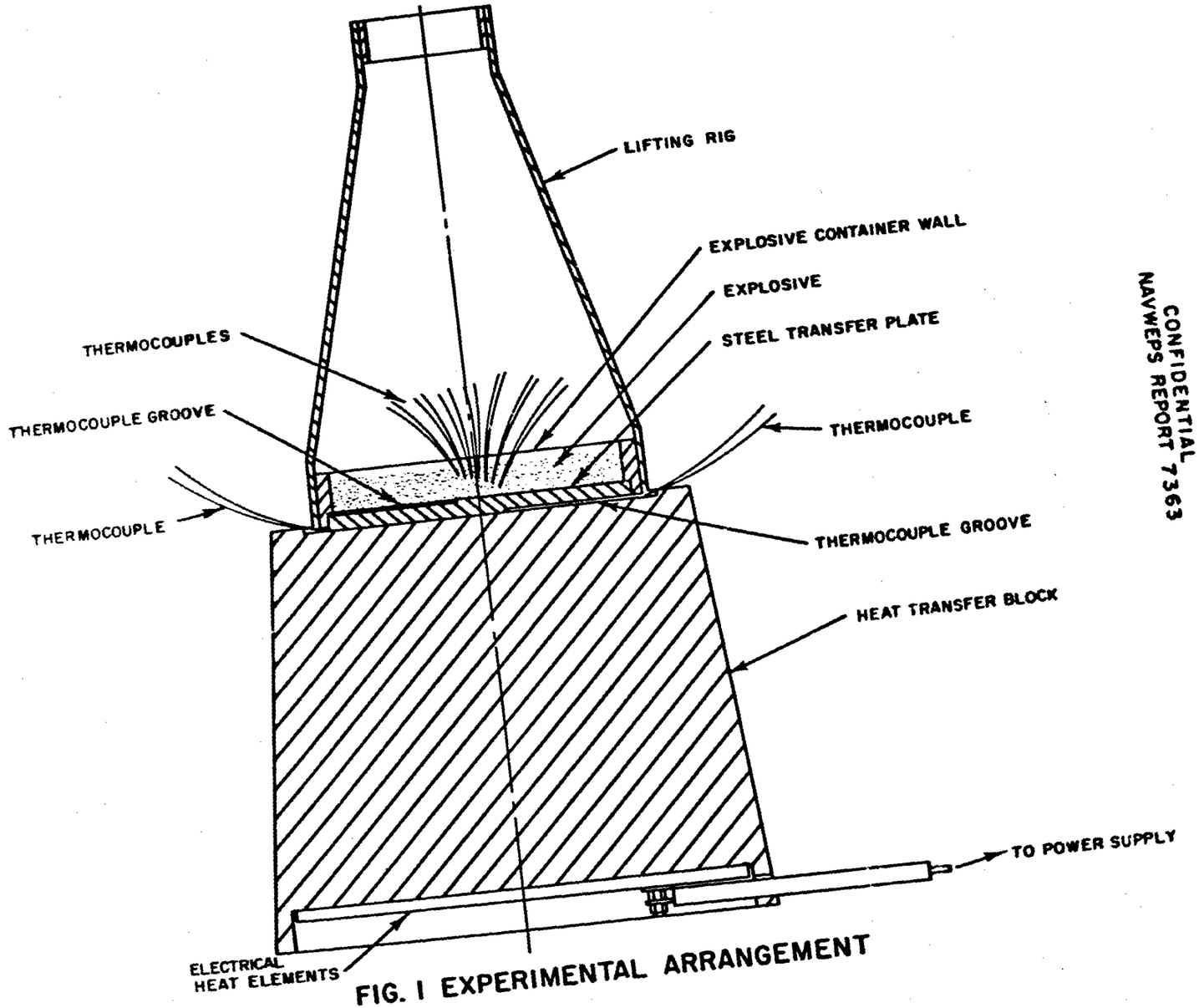

FIG. 1 EXPERIMENTAL ARRANGEMENT

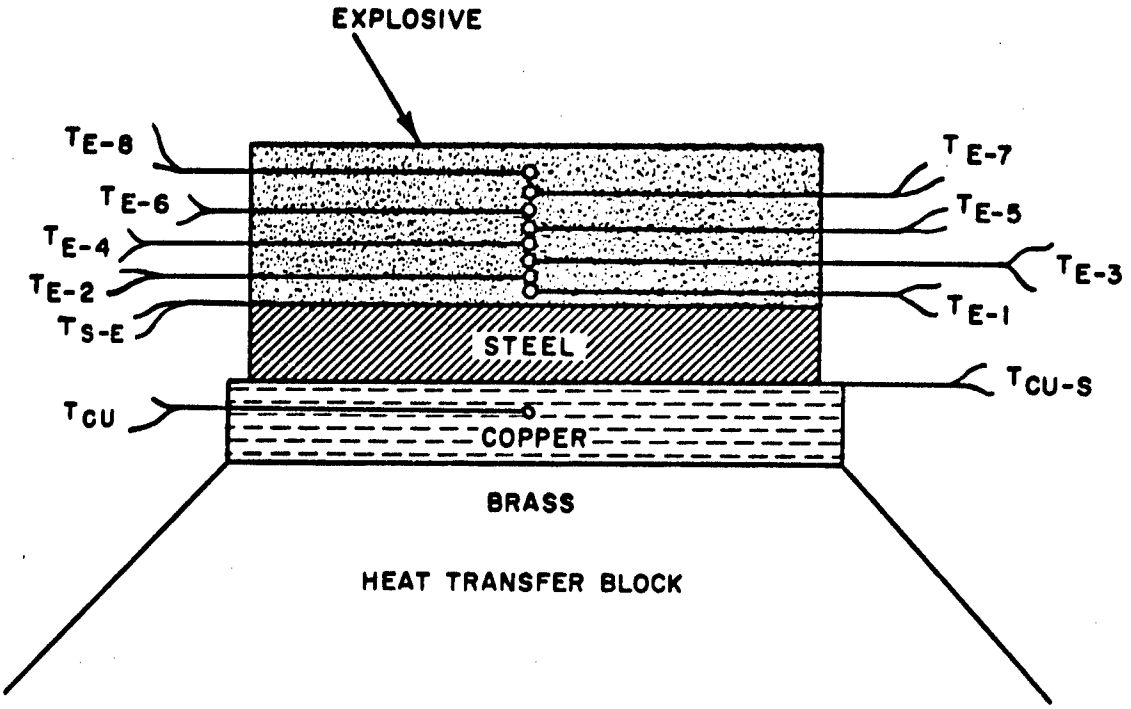

FIG. 2 THERMOCOUPLE DESIGNATIONS

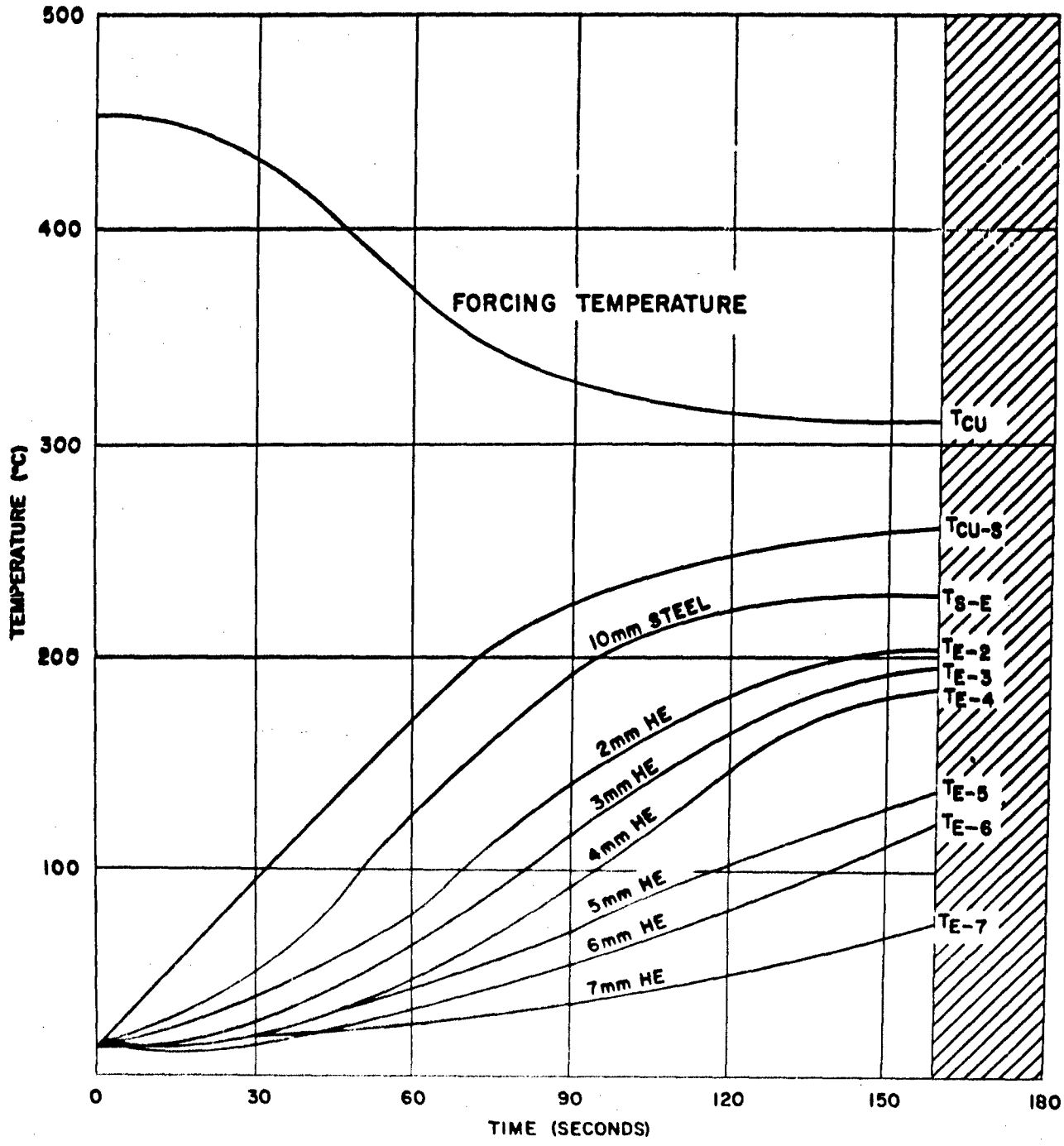

FIG. 3 DEFLAGRATION OF TNT. INITIAL FORCING TEMPERATURE, 456°C.

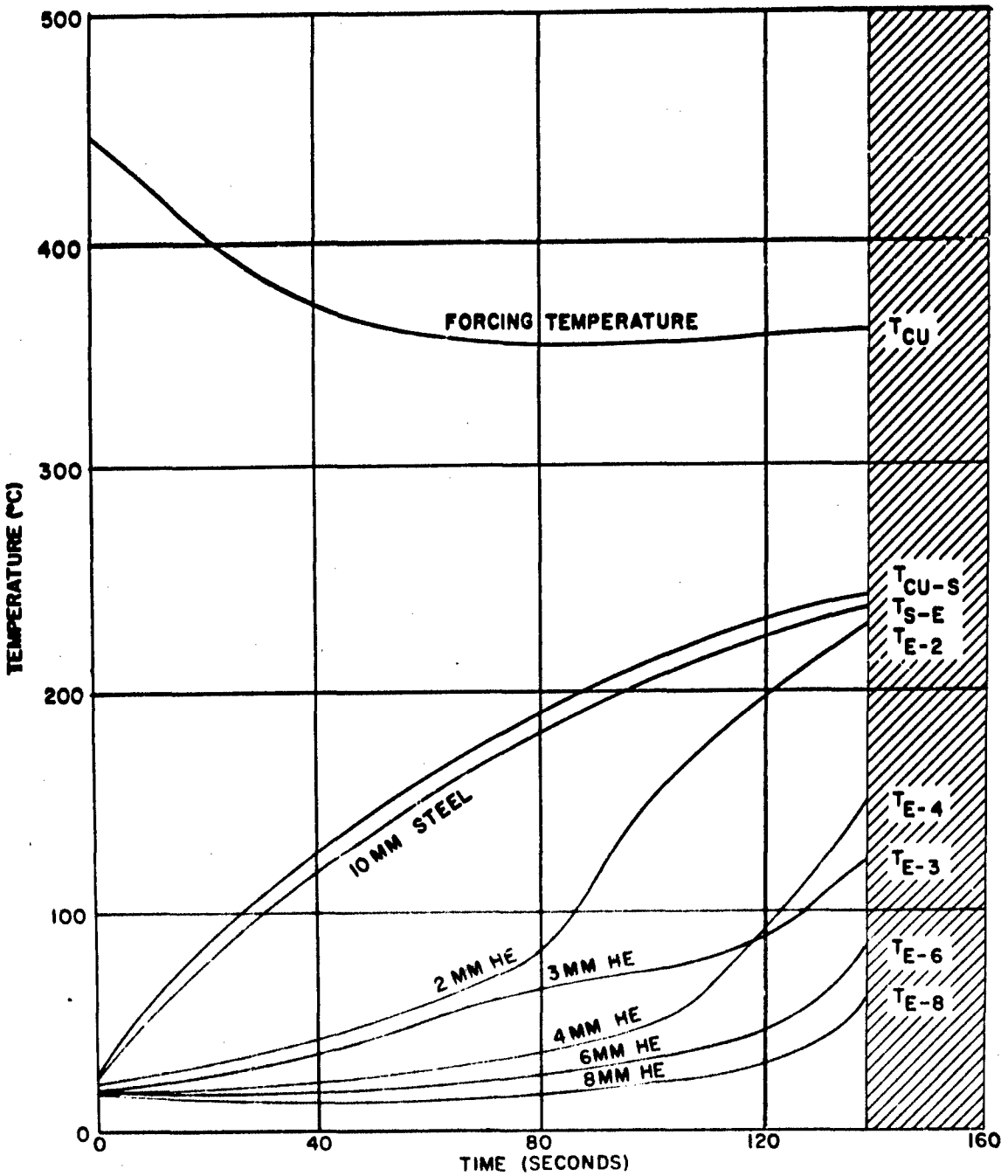

FIG. 4 DEFLAGRATION OF PENTOLITE. INITIAL FORCING TEMPERATURE, 444 °C.

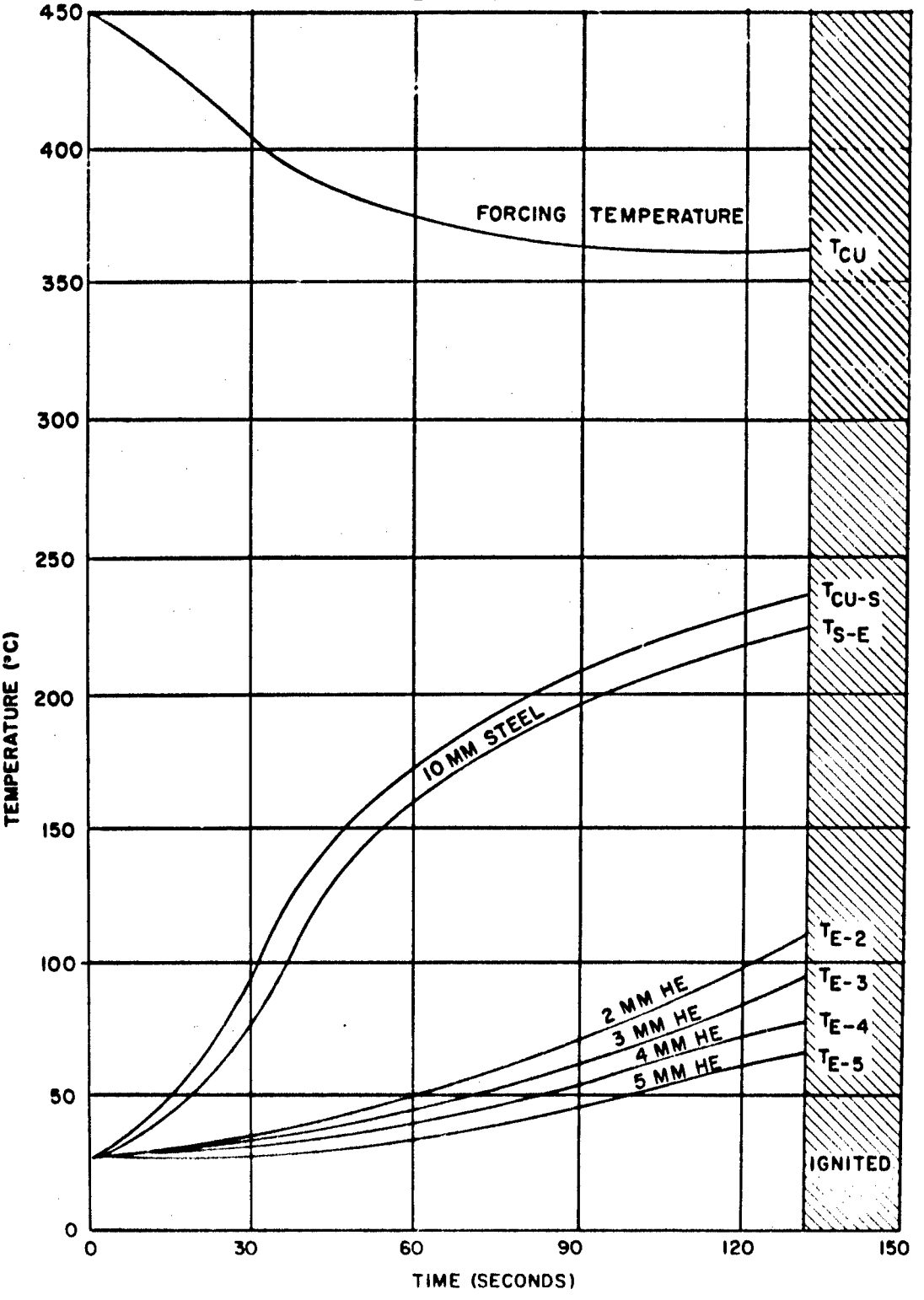

FIG. 5 TETRYL. DEFLAGRATION OF SAMPLE 2. INITIAL FORCING TEMPERATURE, 450°C.

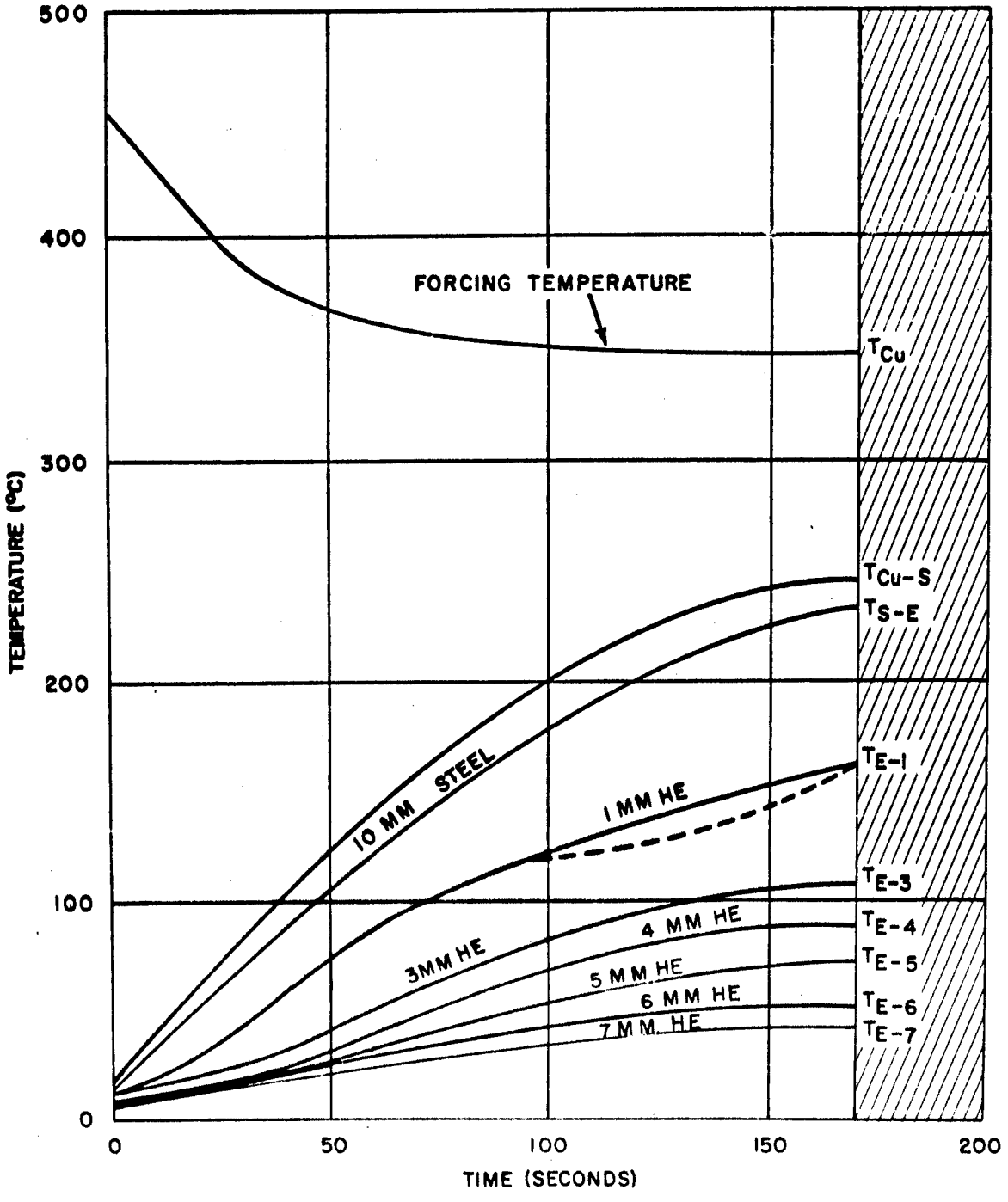

FIG. 6 H-6. DEFLAGRATION OF SAMPLE I. INITIAL FORCING TEMPERATURE, 457 °C.

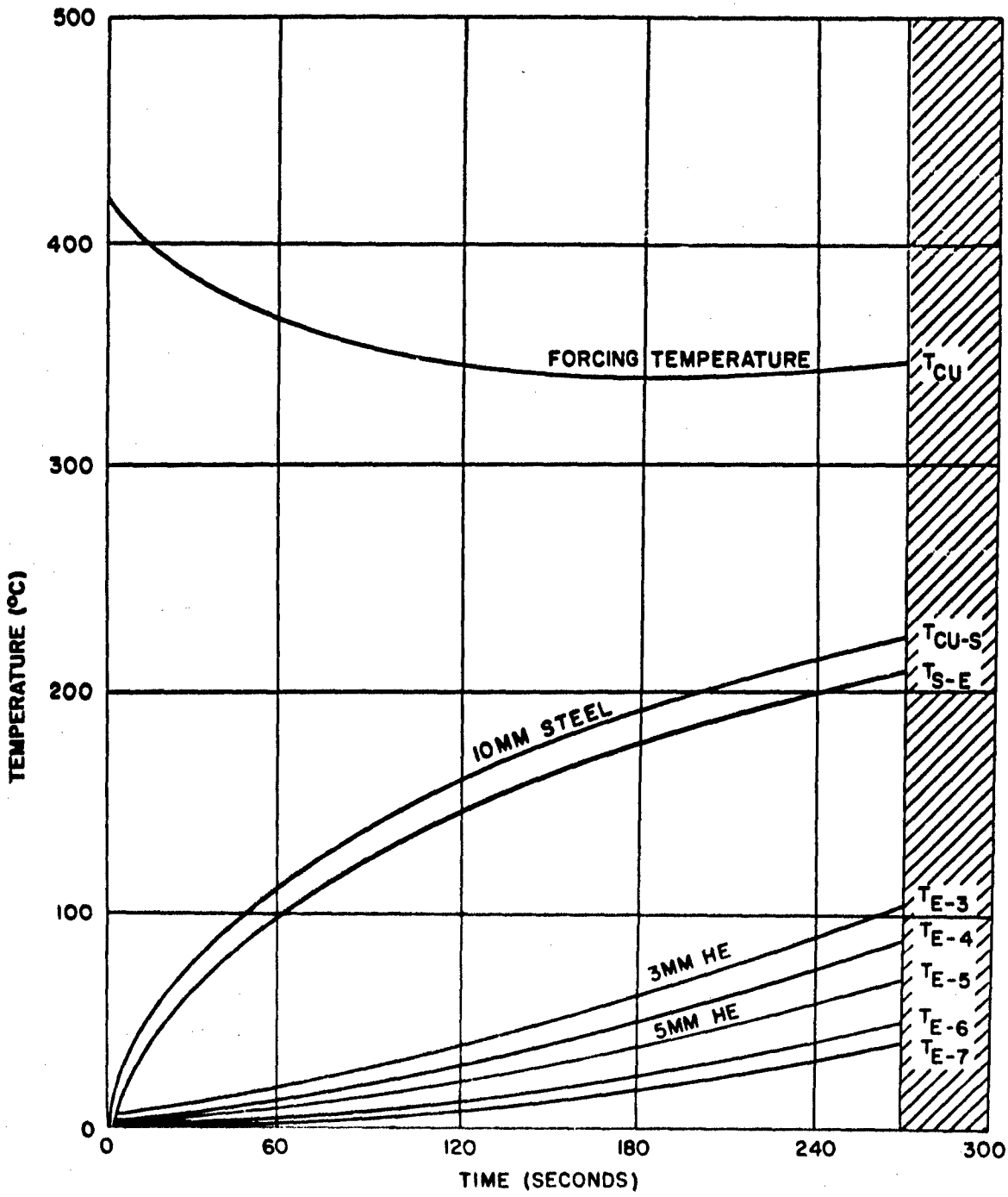

FIG. 7 PBX N-1 DEFLAGRATION OF SAMPLE I. THIRD THERMAL CYCLE. INITIAL FORCING TEMPERATURE, 424°C.

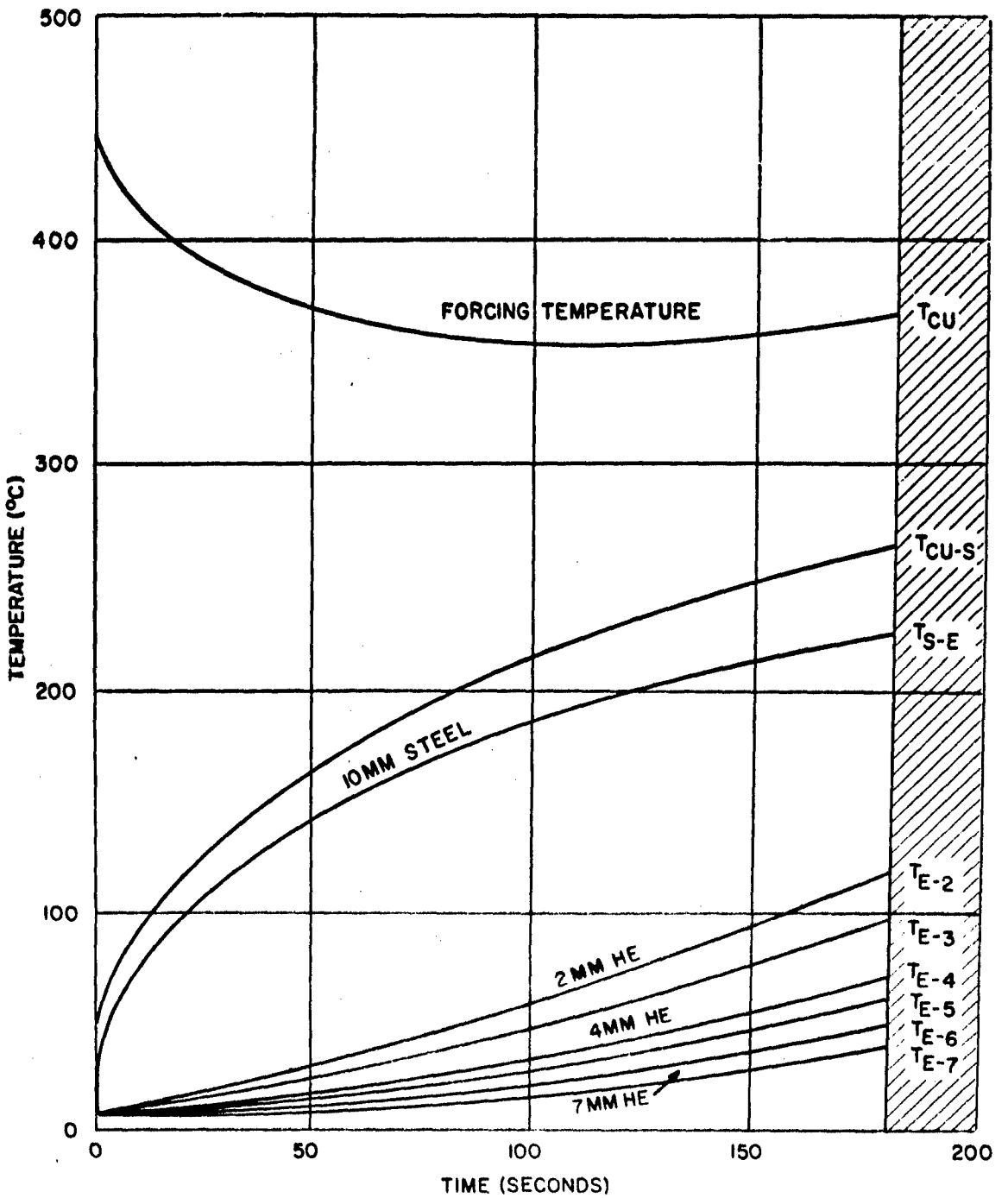

FIG. 8 PBX N-1 DEFLAGRATION OF SAMPLE 2. FOURTH THERMAL CYCLE. INITIAL FORCING TEMPERATURE, 455°C.

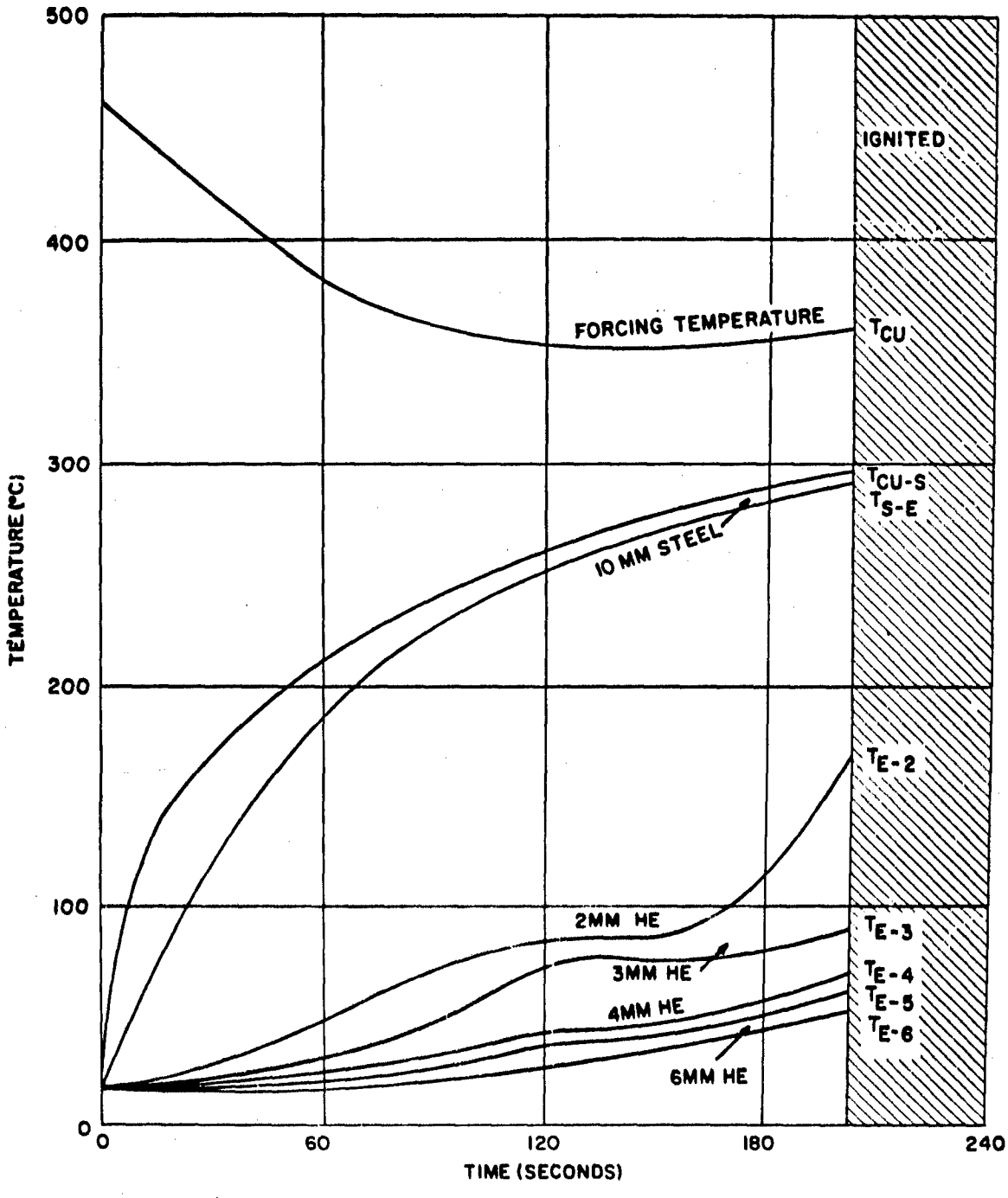

FIG. 9 DEFLAGRATION OF COMPOSITION B. INITIAL FORCING TEMPERATURE, 458°C.

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Naval Ordnance Laboratory, White Oak, Md.
(NAVWEPS report 7363)
THE THERMAL BEHAVIOR OF EXPLOSIVES SUBJECTED TO SIMULATED AERODYNAMIC HEATING, III (U), by N.L. Coleburn and B.E. Drimmer. 25 July 1961. 10p. charts, tables. Task RUME 3E012/212 1/F008 10 004. CONFIDENTIAL

Ignition time and heat flow have been measured for six military explosives, tested in one-dimensional, unconfined analogues of cylindrical, steel-cased warheads. When a temperature of 455°C was applied to the outer surface of the 1-cm thick warhead case, the explosive ignition times (in seconds) were:

Tetryl — 135 TNT — 164 PBX N-1 — 180
Pentolite — 139 H-6 — 169 Comp B — 202

Abstract card is confidential
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1. Explosives - Aerodynamic heating
2. Explosives - Ignition
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5. Pentolites
6. Explosives - H-6
7. Explosives - Composition B
I. Title
II. Coleburn, Nathaniel L.
III. Drimmer, Bernard E., jt. author
IV. Project

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